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Wonogiri Reservoir Sedimentation as Influenced by Change of Catchment Characteristics

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ABSTRACT:

The rate of erosion and sedimentation of Wonogiri Reservoir is higher than planned, so that the reservoir storage capacity decreases rapidly. The sedimentation problem of Wonogiri Reservoir has reached the critical condition where reducing the sediment entering the reservoir is no longer effective that caused sedimentation had reached the intake structure. This paper presents the result of studies on the dynamics of the Wonogiri Reservoir sedimentation. Series of data on monitoring reservoir bed dynamics have been used to analyze the sedimentation rate and series of bathymetry map have been used to discuss the deposition pattern. Evacuation of the sediment from the reservoir has been carried out in 2003 by means of dredging. The dynamics of the reservoir sedimentation during 1993, 2004, 2005, and 2011 are performed, and the results show that in 2011 the total reservoir capacity remains 67% whereas the dead storage capacity remains 50% of the initial capacity. The comparison of the aforesaid dynamics with the change in catchment characteristic is discussed and suggests necessity of integrated countermasures on both catchment and reservoir management.

Keywords: reservoir sedimentation, deposition pattern, integrated countermasures.

1. INTRODUCTION

The Wonogiri Reservoir is located in the Southeast part of the Central Java province of Indonesia (Figure 1). Location of the reservoir is on a mountainous area, since it is the Upper part of the Bengawan Solo river basin. Area of reservoir watershed is 1,305 km^2 consists of eight sub watersheds. The Wonogiri dam was constructed in 1980 and Impoundment December 1981. The reservoir began operation in November 1982. The purposes of reservoir are for flood control, water supply for industrial and drinking water, irrigation, hydropower, fisheries and tourism and maintenance of minimum flow the Bengawan Solo River. Reservoir design life is 100 years, with original total storage of 730 MMC. 220 MMC of the reservoir storage at the elevation +135.3 m up to +138.3 m is allocated for flood control and 440 MMC of the reservoir water for water supply at the elevation of +127m up to +136 m. 120 MMC of the reservoir storage is purposed as the dead storage at elevation below +127 m.

Figure 1. Map of the Wonogiri Reservoir (JICA, 2007a)

Almost all parts of the Indonesian are considerable rapid inpopulations'growth, and the lands are utilized very intensively. Agricultural and non-agricultural land uses such as settlements, transportations, industries, are two types of land utilizations. Similar with other reservoirs, erosion at catchment area of the Wonogiri Reservoir caused sedimentation problem (Mardjono and Sutadi, 1987). Most of reservoirs in Java Island have sedimentation rate higher than estimated sediment rate, so that the reservoir storage capacity decrease faster than planed capacity. The Wonogiri Reservoir sedimentation rate of 15.2 MMC/year, it is equal to 1.4 %/year of the reduction rate for reservoir capacity. It is a high rate for a reservoir sedimentation rate (Hastowo, 2003). The Wonogiri Reservoir problem is not only rapid decreasing in the reservoir capacity, but also spatial sedimentation problems such as sedimentation in the front of reservoir intake. Sedimentation leads to reduction of the reservoir's economic life, disruption of operations due to intake clogging from The Keduang River debris and a decrease in the water reservation ability, especially during the dry season (JICA, 2007a). According to sediment measurements in the year 2011 by Perum Jasa Tirta I (PJT I) shows the remaining effective capacity of the reservoir is only 70 % from the initial design reservoir capacity (Wulandari et al., 2012).

Reservoir sedimentation in the reservoir dead storage is one aspect for determining economic life of reservoir. If the capacity of dead storage is full then the efficiency of reservoir operation will be disrupted and eventually ended reservoir function. These items are three aspects may influence the rate in reducing reservoir capacity: (a) the quantity of sediment inflow, (b) the percentage of sediment trap, and (c) the deposit sediment density (Loebis et al., 1987). Regular sediment monitoring or measurements need to be performed for determining and estimating the rate of sedimentation. An evaluation of reservoir sediment inflow and spatial reservoir sedimentation is required when the sedimentation rate exceeds the rate of sedimentation plans.

Based on monitoring of reservoir bottom elevation, the dynamics and deposition pattern of Wonogiri Reservoir sedimentation presents and discusses. The comparison of the dynamics with the change in catchment characteristic is discussed and suggests necessity of integrated countermasures on both catchment and reservoir management.

2. DYNAMICS SEDIMENTATION PROCESSES

The reservoir sedimentation monitoring was conducted since 1981. In the period 1981 – 1988, the reservoir sediment inflow is estimated based on measurements of sediment in the six major tributaries. The total sediment volume into the Wonogiri reservoir in 1981-1988 was estimated 9.63 million m^3 . Thus the annual average sediment inflow was estimated around 1.2 million m^3/year. In 1985 and 1990, the reservoir bathymetry measurements measured by echosounding. The estimated sediment deposits (loss of storage volume below El. 138 m) were around 86.2 million m^3 in 1981-1985 and 156.4million m^3 in 1980-1990. The estimated annual average sediment deposition is around 15.6 million m^3/year in 1981-1990 (JICA, 2007b).

Subsequent sedimentation monitoring held in 1993 – 2011, the reservoir bathymetry measurements using echosounding. Figure 2 shows the H-V curve and the H-A curve of Wonogiri Reservoir in periods 1980 - 2011. Based on Fig. 2 it can be seen the storage and the reservoir surface area decreases from time to time. Table 1 shows sedimentation rate varies from time to time with the average sedimentation rate 7.74 MMC/ year. The highest sedimentation rate of 35.62 MMC / year occurred during 2005 to 2008. The sediment inflow are not only settle in the dead storage, the sediment inflow settles on the entire surface of the reservoir bed. Sediment that settles on effective storage and flood storage will reduce capacity of the effective storage and the flood storage, respectively. The reservoir sedimentation rate is higher than planned so that at the age of 31, half of dead storage capacity has been filled with sediment. If the sedimentation rate remained in the range of 7.74 MMC/ year, total storage will be full on a half within the next seventeen years. Figure 3 shows decreasing the Wonogiri Reservoir storage capacity. Up to the year 2011 remaining of total reservoir capacity is only 67% and remaining of dead storage capacity is only 50%. Effective storage capacity and flood storage capacity also decreased, their remaining capacity are 69 % and 57 %, respectively. Figure 4 shows the sedimentation in the front of the intake. This was a critical condition since the sedimentation had reached the intake structure in such that release through the intake could not be carried out. Horizontal intake bell mouth easily clogged sediment because it located in the dead storage zone.

Figure 5 shows the sediment deposition in each zone. Negative values indicate that in the zone occurs bed surface erosion. Positive values indicate that in the zone occurs sediment deposition. During 1993 - 2005, in the flood storage zone sediment deposition does not occur. Sediment that settles in the dead storage zone decreased, this is due to dredging around the intake. Sediment that settles in the effective storage zone increased. During 2005 - 2011, sediment deposition occurs in all zones. In the dead storage zone, deposition of sediment decreased. In the flood storage zone and effective storage zones, deposition of sediment increased. The increase in deposition of sediment that settles in flood storage zone and effective storage zone will reduce reservoir function. Generally, deposition of sediment in Wonogiri Reservoir increase. Dredging is done not greatly affect returns dead storage capacity, because the volume of dredged is small and dredging only done around the intake.

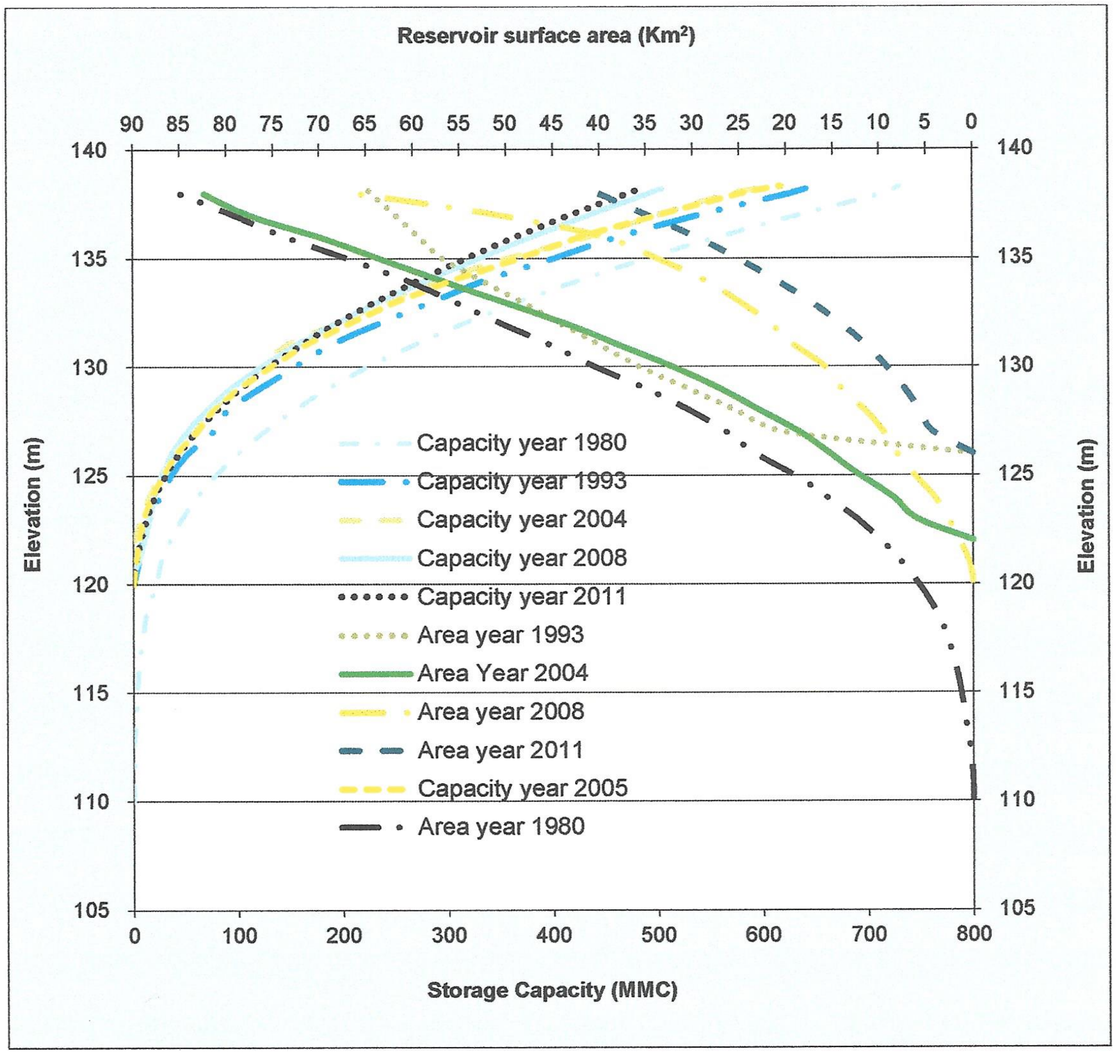


Figure 2. H-V Curve and H-A Curve of Wonogiri Reservoir (BBWS Bengawan Solo and Perum Jasa Tirta I)

Table 1. Sedimentation rate of Wonogiri Reservoir

Description	Unit	Year					
		1980	1993	2004	2005	2008	2011
Sediment below El. 138.3 m	MMC	0.00	80.00	32.00	2.00	106.55	19.33
Sediment dredged volume	MMC	0.00	0.00	0.35	0.10	0.30	0.30
Kumulatif sediment inflow	MMC	0.00	80	112.35	114.45	221.30	240.93
Sedimentation rate	MMC/year	0.00	6.15	2.94	2.10	35.62	6.54
Average sedimentation rate	MMC/year	7.74					

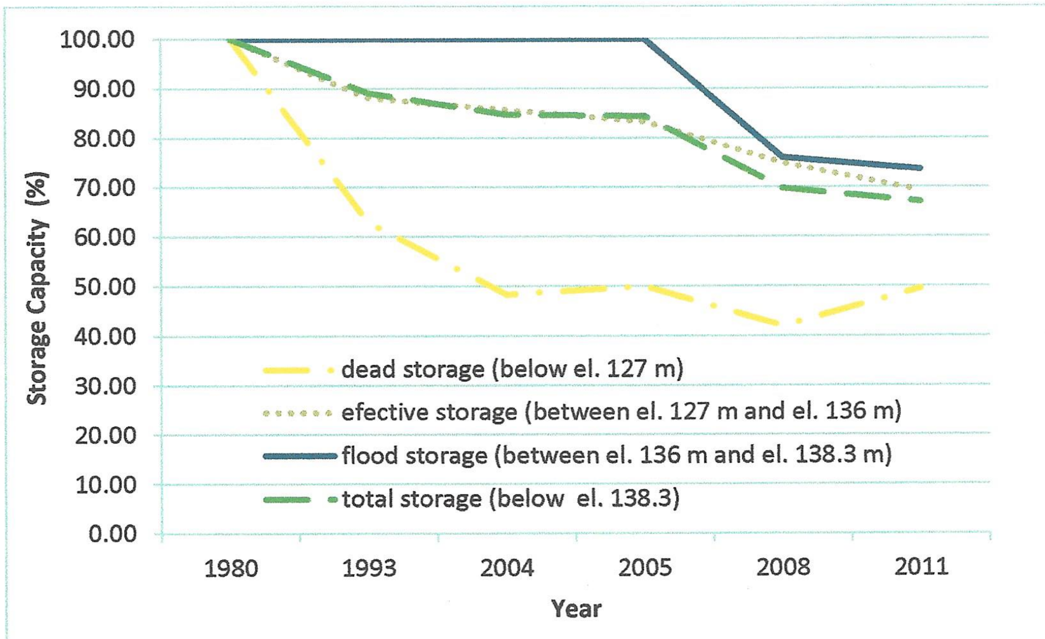


Figure 3. Decrease of the Wonogiri Reservoir storage capacity

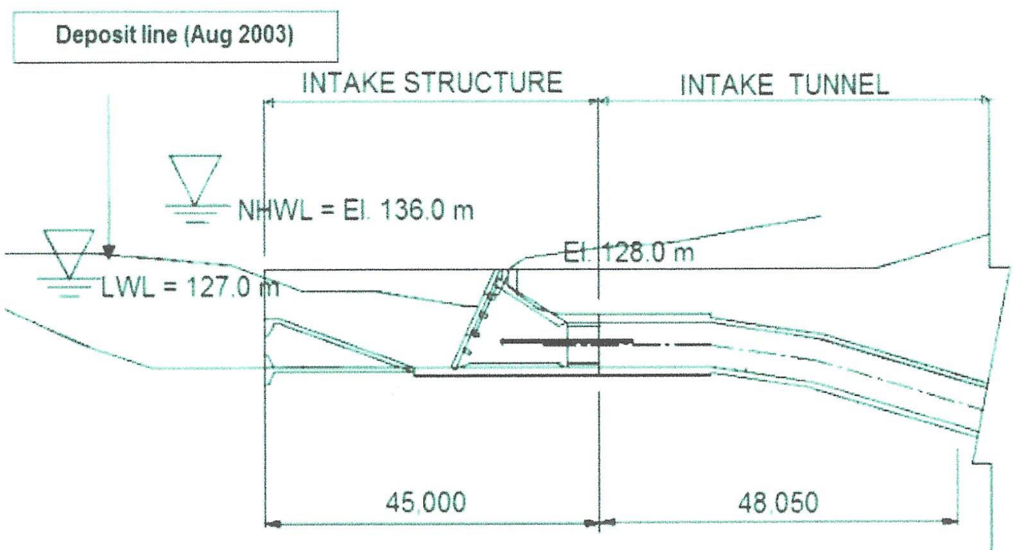


Figure 4. Sedimentation in front of the intake (JICA, 2007b)

Figure 6 shows the bathymetry map of Wonogiri Reservoir year 1993, 2004, 2005 and 2011 base on measurement by Balai Besar Wilayah Sungai Bengawan Solo, JICA and Perum Jasa Tirta I. The darker color indicates the deeper of reservoir depth. In 1993 the pattern of sediment deposition in the longitudinal direction forms puddles, the deepest part in the middle. Around the intake has occurred sedimentation, the depth became shallower. In 2004 there has been a change in the pattern of sediment deposition. Around the intakes look deeper due to the dredging of sediment that began in 2003. From the Keduang river mouth, it is seen groove toward the intake. In the longitudinal direction, the pattern of sediment deposition has the deeper part in the middle. In 2005, the depth around the intake until Keduang river mouth still deep. In the longitudinal direction, the pattern of sediment deposition has the deeper part in the middle and toward the dam forming a groove. The around intake becomes shallower. In 2011 deposition occurs uniformly across the surface of reservoir zone. Although dredging around the intake is done, the depth around the intake still shallow. This suggests that the dredging is done can not offset sedimentation rate. In the longitudinal direction, the pattern of sediment deposition form puddles with the deepest part in the middle. In tributary sediment deposition occurs toward the upstream direction as a result of backwater. Finer sediments are carried out further into the reservoir. Due to the wider part of the river mouth, velocity decreases and sediment settles easily. So this section becomes shallow. At the Keduang river mouth, this condition becomes critical due to the intake clogging. In general, the pattern of sediment deposition have a tendency to form puddles in the longitudinal direction, this is due to the reservoir consists of several tributaries (dendritic). Sediment that settles on flood storage zone and effective storage zone may occur due to reservoirs operated at high water level during floods. So that the sediment settles in the dead zone storage, the reservoir should be operated at low water levels during floods. This operations need to be reviewed further because it will affect the function of reservoir as a flood control.

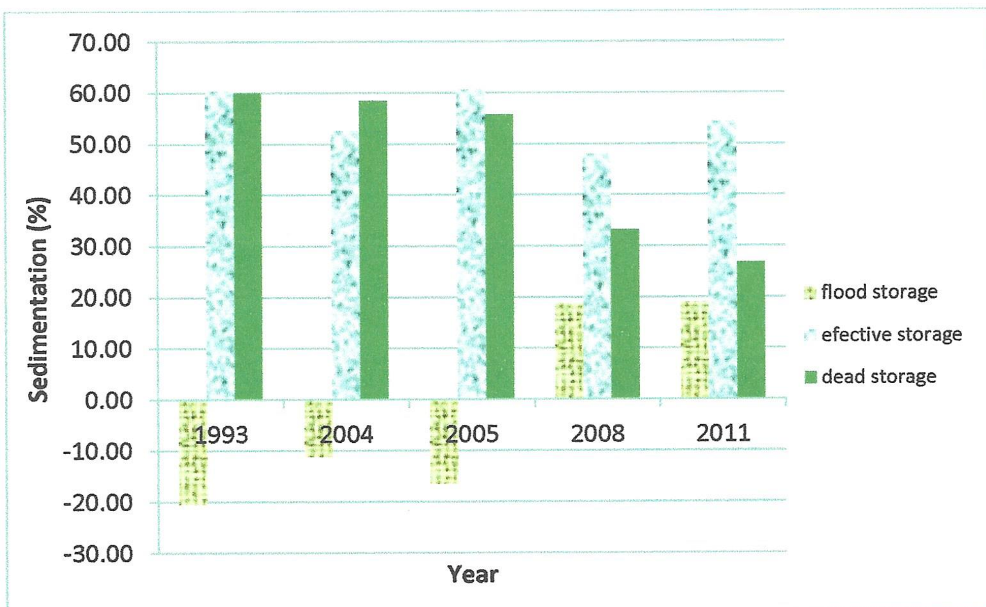
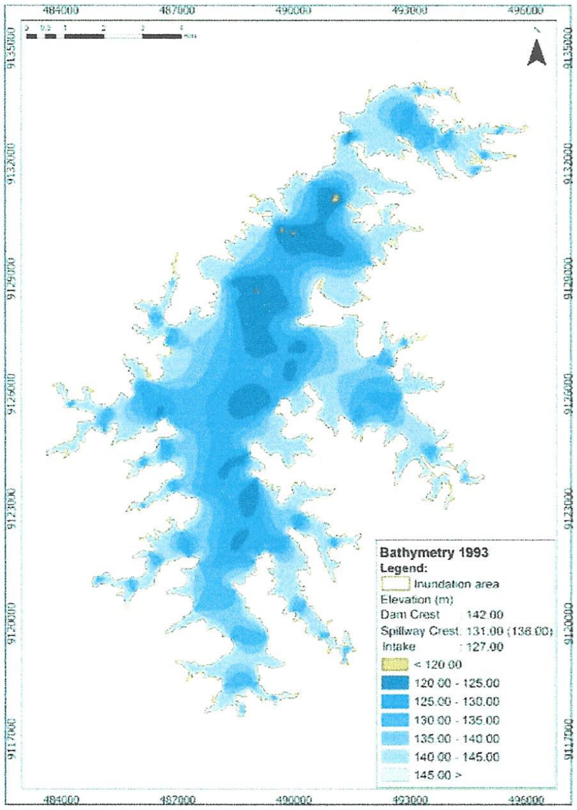
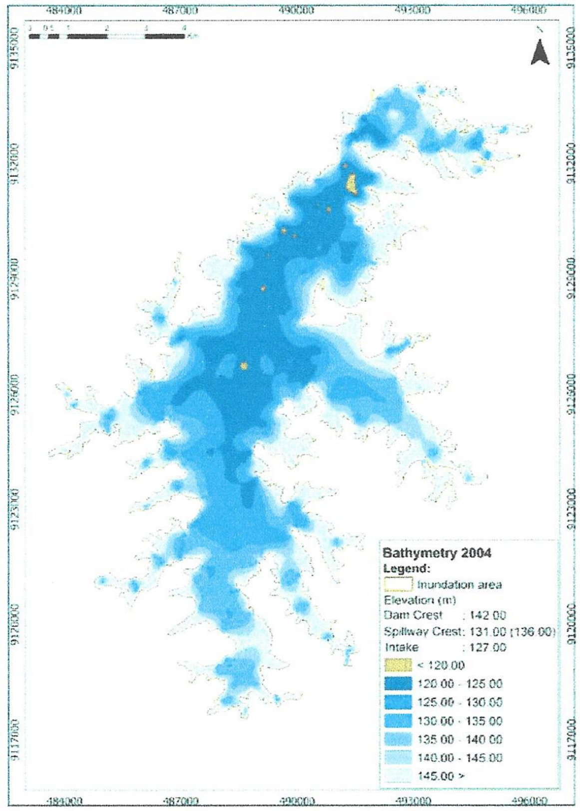


Figure 5. Sediment deposition in each zone year 1993 - 2011

Key questions in the assessment of degraded tropical watersheds and the potential for control of sediments can be posed : 1). What is the natural background rate of erosion and sediment movement which can be expected? 2). What has been the sediment contribution of human activities and how capable are we of controlling them ? 3).What is the potential for storage within the basin of eroded material, whether of natural or human origins? (Nagle et al, 1999). Wonogiri Reservoir was built on watershed which was basically had a high erosion. According to Notohadiprawiro et al. (1981) the western part of Wonogiri watershed was eroded almost two times more weight than the eastern part of Wonogiri watershed. It is caused by two factors : the more erosive rainfall and soil erosion are more sensitive. In the western region, the erosion was 412.2 T/ha/year. In the eastern region, the erosion was 216.1 T/ha/year. The average of erosion was 314.2 T/ha/year.



A). Year 1993



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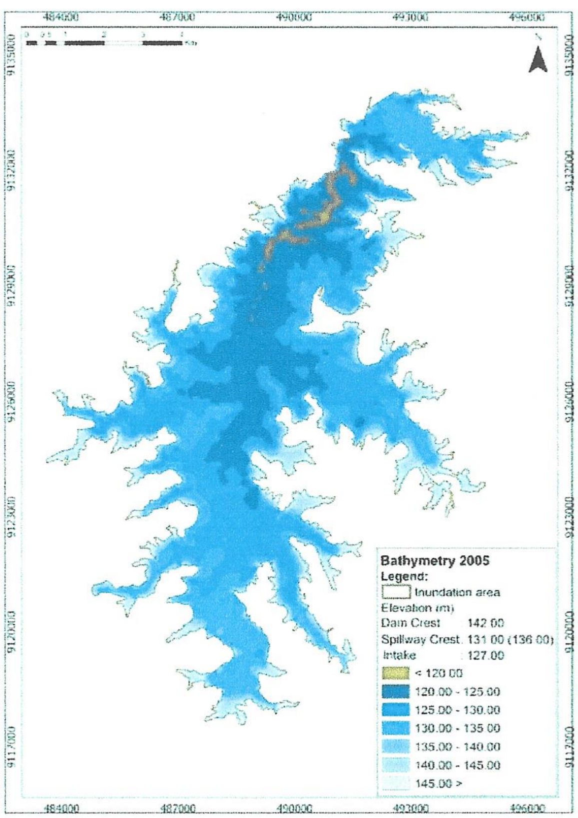
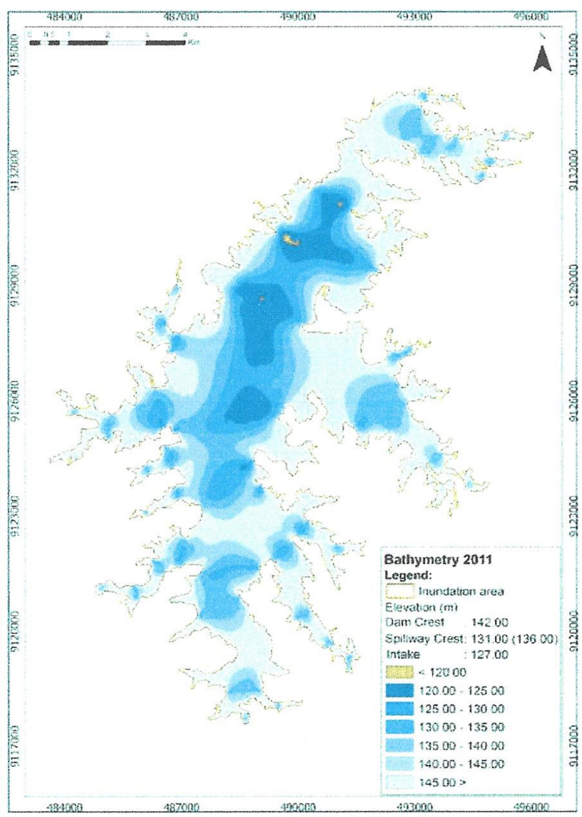


C). Year 2005



D). Year 2011

Figure 6. Bathymetry Map of the Wonogiri Reservoir

According to Puslitbang Pengairan (1986) Tirtomoyo sub watershed and Bengawan Solo sub watershed are sub watershed with heavy erosion. Severe erosion also occurred in the Wuryantoro sub watershed but this does not significantly affect the depth of Wonogiri Reservoir because the sediment was trapped by Parangjoho reservoir. Base on Abdurrosyid and Santosa (2004) erosion in Wonogiri Reservoir watershed is mainly influenced by vegetation cover and land conservation. Furthermore, the amount of erosion that occurs on each sub-watershed is affected by sub-watershed area. Increasingly the area of watershed causes higher erosion. Sedimentation rate between the years 1990 - 2000 had a significant decrease, as the positive impact of soil conservation and land rehabilitation carried out in 1987-1994. But the reservoir sedimentation rate of 2.63 mm/year remained above the threshold by 1.2 mm/year. Base on JICA (2007a) Erosion that occurs in sub-watershed ranged between 5.86 – 19.50 mm/year, exceeding the allowable erosion of 1 mm/year. The highest erosion occurred in Tirtomoyo sub-watershed, followed by Bengawan Solo sub-watershed, Temon sub-watershed, Keduang sub-watershed, Remnant sub-watershed, Ngunggahan sub-watershed, Wuryantoro sub watershed and Alang sub-watershed. Though erosion is not the highest in Keduang watershed but Keduang watershed supply the highest sediment yield, it is due to the largest area of sub watershed.

Conversion of sedimenting reservoir into sustainable resources which generate long term benefits requires fundamental changes in the way they are designed and operated. It requires that the concept of a reservoir life limited by sedimentation be replaced by a concept of managing both water and sediment to sustain reservoir function. Sustainable use is achieved by applying the following basic sediment control strategies are reduce sediment inflow, route sediments, sediment removal, provide large storage volume and sediment placement (Morris and Fan, 1997). Reservoirs built on the river that each has different sediment behavior so the handling of the sedimentation also different. To obtain maximum results, several methods can be combined (Liu et al, 2002; Wang and Hu, 2009).

The Wonogiri Reservoir sedimentation management which has been and will be implemented has been to combine several methods. There needs to be an evaluation of the sedimentation management program that has been done before, as the basis for moving the program of a new sedimentation management. To deal with the most important reservoir sedimentation is addressing a source of sediment. To handle a source of sediment can be done with conservation, both technically or vegetation. Conservation of vegetation takes a long time so that while conservation of vegetation can not function technically addressed first. And this conservation should involve and benefit local communities so ensure the sustainability of the program. The construction of small dams in the upstream sub-watershed is necessary to trap the sediment. Reservoir operation need to be evaluated to improve the pattern of sediment deposition and further more to handle sedimentation.

4. CONCLUSIONS

The reservoir sedimentation rate faster compare to design rate, the remaining reservoir storage in the 2011 is only 67% and the remaining capacity of dead storage is only 50%. Excavation of the reservoir sediment cannot produce a great result for maintaining the reservoir storage capacity. Wonogiri Reservoir is a unique reservoir, because the reservoir water inflow came from river mouths that located around the reservoir. Therefore, sediment input will deposit at the river mouth around the reservoir. As a result 73% of the sediment settles in the effective storage zone and the flood storage zone, and the sediment settles in the dead storage zone only 27%. Up to now, sedimentation management of the Wonogiri Reservoir is not success to preserve the reservoir capacity. The concept of a reservoir life limited by sedimentation must be replaced by a concept of managing both water and sediment to sustain reservoir function. A special mathematical model is required to map spatial dynamic sedimentation pattern for designing capacity of a new reservoir with similar topographical condition and river inflow with the Wonogiri Reservoir.

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